first, the actual magnitude of the disturbance itself, and next, upon the distance of the Earth from the direction of maximum effect. We should find, as we actually do, that when the average was taken of a large number of cases the frequency of magnetic storms and their intensity would correspond to the size of the solar spots; but at the same time we should also find, as we do, that there would be a wide margin of irregularity in special instances. It is in perfect accord with this suggestion that we actually find at the moment of commencement of the nineteen great storms examined that the most important spot on the Sun was always found within a restricted area on the surface. If the influence of the spot were exactly equal over the whole sphere of which it was the centre it is difficult to understand why this relation should have shown itself.

In the foregoing remarks I have confined myself entirely to the spots. We have at present no sufficient material for a similar discussion in the case of faculæ, prominences, or flocculi. In the ordinary way we see prominences only round the limb, faculæ only near it; of flocculi we have not yet enough observations; spots, on the other hand, we see wherever they exist in any part of the hemisphere turned towards us, and our knowledge of them may be said to be fairly complete. Further, the four different orders of phenomena are not independent, but interdependent; and concerning the first three we know that they go through their variations in the course of a solar cycle in substantial accord. At the present time, whatever may be the case in the future, spots are the most easily observed and most fully observed of all the various phenomena which can afford us any index of the solar activity.

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## *Suggested Connection between Sun-spot Activity and the Secular Change in Magnetic Declination.* By Mrs. Walter Maunder.

(*Communicated by E. Walter Maunder.*)

A connexion between the Sun and terrestrial magnetism has been recognised as existing in the following relations :—

(1) Daily.—The diurnal range of magnetic declination, dip, and intensity, according to the hours of local mean time, when by means of the Earth's rotation different parts of its surface are exposed to the action of the Sun's rays.

(2) Yearly.—The annual variation in the amount of the diurnal range corresponding to the variation in the presentation of any particular locality to the Sun's rays in the course of the year.

(3) Cyclical: "Eleven-year" Period.—Variation in the

amount of the diurnal range synchronous with the variation of the spotted area of the Sun.

In terrestrial magnetism this cycle is shown in the variation of the diurnal range, both of magnetic variation, dip, and intensity, and is evidenced, moreover, both (*a*) by the frequency of storms and (*b*) by the variation of the diurnal range when cleared of storms.*

On the Sun the "eleven-year" cycle is shown by sun-spots, faculæ, prominences, and corona, and in the case of sun-spots is evidenced both (*a*) by the frequency of giant spots alone and (*b*) by the variation in the spotted area of the Sun when cleared of giant spots.

These three periodic variations in the Earth's magnetism, which are thus known to vary in sympathy with the Sun, form, according to Mr. L. A. Bauer, but a small part of the whole magnetic force of the Earth—less than 5 per cent.—and they are generally ascribed to electric currents in the upper regions of the atmosphere. At least 95 per cent. of the Earth's magnetism is to be referred to causes within the crust, largely to a system of electric currents imbedded deep within the interior of the Earth. In particular the secular change in the three elements of terrestrial magnetism (declination, dip, and intensity) should probably be referred largely to the effect of secondary electric currents generated within the Earth by its rotation round an axis not coincident with its magnetic axis.

It being thus the case that the secular change in the Earth's magnetism seems primarily to be due to internal causes, it is all the more interesting to note that certain critical changes in the Earth's magnetism appear to have synchronised with certain critical changes in the activity of the Sun.

The following tables show the secular change in the magnetic declination at London (long. 0°., lat. 51½°) for every twenty years from 1540 to 1900, and for Baltimore (long. 76½° W., lat. 39½° N.) from 1640 to 1900:—

| Year. | London. | Baltimore. | Year. | London. | Baltimore. |
|---|---|---|---|---|---|
| | ° | ° | | ° | ° |
| 1540 | 7·2 E. | ... | 1740 | 15·3 W. | 3·2 W. |
| 1560 | 9·6 E. | ... | 1760 | 19·6 W. | 2·0 W. |
| 1580 | 10·9 E. | ... | 1780 | 22·7 W. | 1·0 W |
| 1600 | 10·1 E. | ... | 1800 | 24·1 W. | 0·7 W. |
| 1620 | 7·3 E. | ... | 1820 | 24·1 W. | 0·9 W. |
| 1640 | 3·3 E. | 5·3 W. | 1840 | 23·2 W. | 1·8 W. |
| 1660 | 0·6 W. | 6·0 W. | 1860 | 21·6 W. | 3·0 W. |
| 1680 | 3·9 W. | 6·1 W. | 1880 | 18·7 W. | 4·3 W. |
| 1700 | 7·1 W. | 5·5 W. | 1900 | 16·5 W. | 5·4 W. |
| 1720 | 11·0 W. | 4·5 W. | | | |

* "On the Relation between Magnetic Disturbance and the Period of Solar Spot Frequency," by Mr. W. Ellis, F.R.S., *Monthly Notices*, vol. lx. pp. 142–157.

In the table for London it will be noted that there is a maximum declination E. about 1580, zero declination about 1660, maximum declination W. about 1810, since which date it has been returning eastward. For Baltimore there was a maximum declination W. about 1680, a minimum declination about 1800, since which date it has been again increasing westward. The diagram (fig. 1) will perhaps show more clearly the path of the point of intersection of the two magnetic meridians. The curve for the period between 1540 and 1640 is drawn

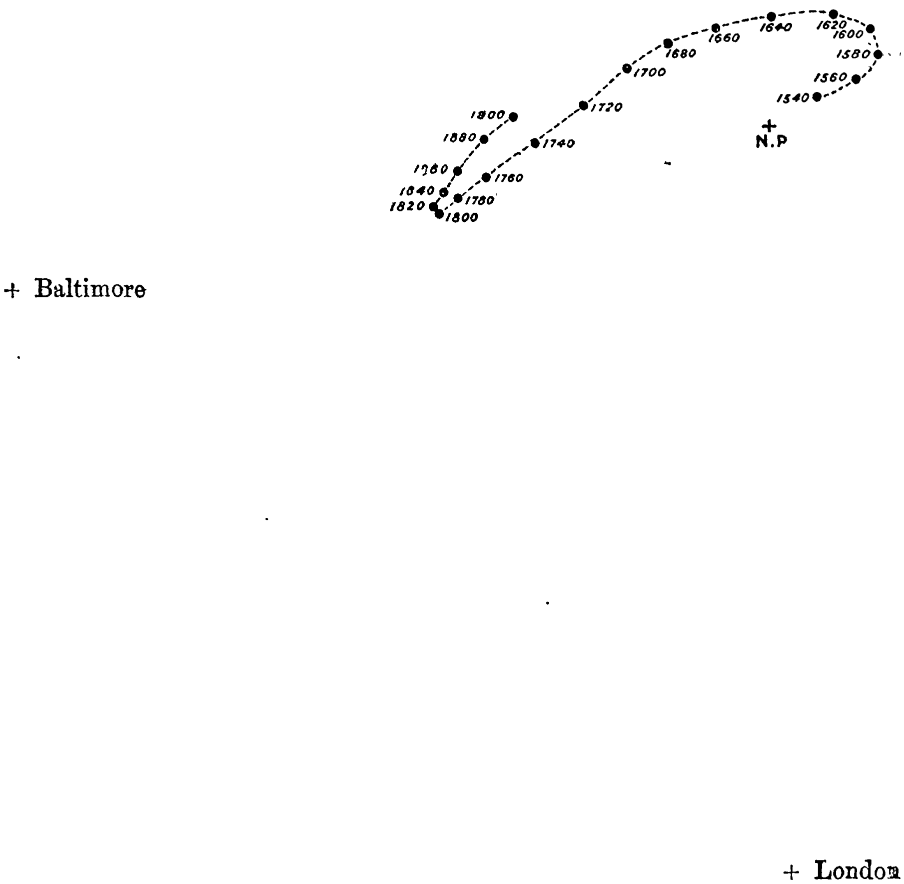
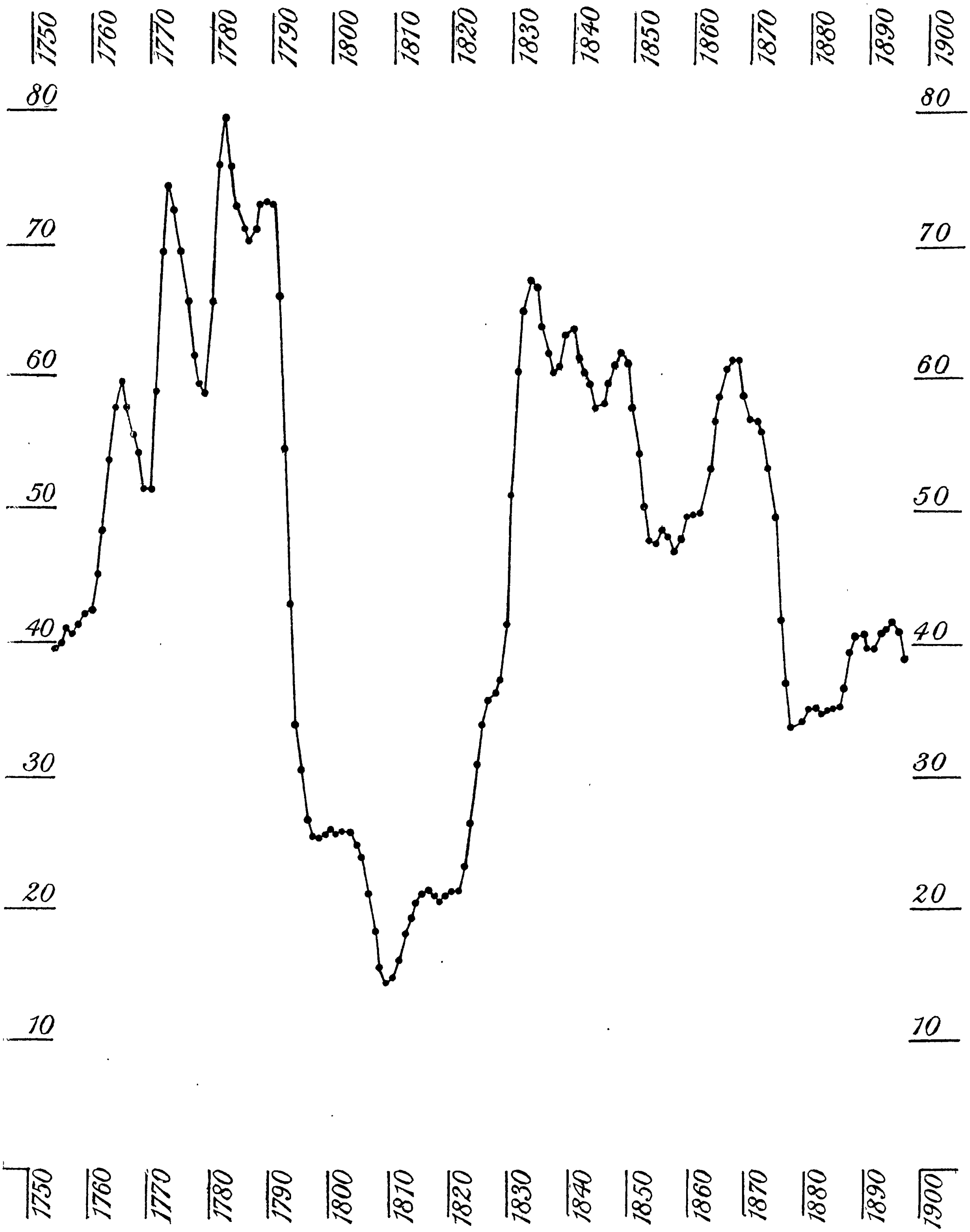



Fig. 1.

on the supposition that the needle at Baltimore varied then in the same manner as it did during the period of observation.

The path of the magnetic pole, as this intersection of the magnetic meridian may perhaps be called, would seem not to be a mere revolution round the geographical pole, but to be more like the swing of a pendulum. Evidently there are nodes or points where the direction of its motion changed about 1580; between the years 1640 and 1680, when it was moving rapidly and was at the same time near the north pole of the Earth; and about 1800.

When other pairs of stations in Europe and America are




PROF. WOLFER'S "RELATIVE SUN-SPOT NUMBERS" SMOOTHED FOR THE "ELEVEN-YEAR" PERIOD.

taken, the curves traced by the intersection of their magnetic meridians is of the same character as that shown by the two selected.

Sun-spots were first discovered in the year 1610, and since that period we know of two striking cases of prolonged solar quiescence. The first was the most pronounced, and lasted from about the year 1640 to about the end of the century, during which period but a single spot now and then appeared even at times when the Sun should have been most active. The "eleven-year" cycle seemed obliterated, and an almost unbroken solar calm prevailed. Auroræ were notedly absent.

The second period of solar quiescence was remarkable, but not so complete. The "eleven-year" cycle could still be plainly traced, but for several succeeding maxima the solar activity was much below the normal; and this was emphasised by the great activity that preceded and followed the period of semi-quiescence. The accompanying diagram, which gives Wolfer's relative spot numbers cleared of the "eleven-year" cycle, will show this plainly (Plate 13). During this period of solar quiescence auroræ were also deficient.

We have, of course, no means of saying what was the state of the Sun's activity earlier than 1610. At that period spots were abundant, but the stationary position eastward of the magnetic declination needle in the years 1580–1600 may also have been marked by a period of quiescence in solar activity and in auroræ.

Prior to 1600 there seems to have been a change in the law of secular change. Mr. L. A. Bauer (in his "Magnetic Tables and Isogonic Charts for 1902") has found both for Rome and for Fayal Island, in the Azores, that there is a marked difference for the fifteenth and sixteenth centuries between the curve as given by the present apparent law of secular change and the full curve as deduced from observations obtained by the aid of early "compass charts."

There is no material for discussing the secular change of any of the magnetic elements in the southern hemisphere, neither are there observations of dip or magnetic intensity for a sufficient length of time in the northern; and these are necessary for a full discussion of the question. As it is, I have been obliged to assume for London and Baltimore that they are uninfluenced by local magnetism, or at least that such local magnetism does not affect the law of secular change. Of this there is no evidence for or against.

To sum up. The ordinary sun-spot cycle has twice been disturbed within the period of observation by long-continued calms. The first and most remarkable took place in the latter half of the seventeenth century; the second at the commencement of the nineteenth. These two periods of solar calm appear to have been answered on the Earth by corresponding periods of absence of auroræ. There was thus sympathy between solar

quiescence and terrestrial magnetism. When the movement of the north "magnetic pole" is considered it appears that at these two very epochs it was passing through two critical points of its path—the first when it was at its nearest approach to the geographical pole, the second when it was at its greatest elongation from it.

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## *The Aurora and Magnetic Disturbance.*

By William Ellis, F.R.S.

In a paper that appeared in the *Monthly Notices* of the Society for 1899 December, on the relation between magnetic disturbance and the period of solar-spot frequency, I showed from the observations of the fifty years 1848 to 1897 at the Royal Observatory, Greenwich, the general relation existing between the period of solar-spot frequency and the frequency of magnetic disturbance in the progression from Sun-spot maximum to Sun-spot minimum, and again from Sun-spot minimum to Sun-spot maximum; and further pointed out that, in addition, there existed in the frequency of magnetic disturbance an annual inequality that has no counterpart in the march of Sun-spot frequency. In a following paper appearing in the *Monthly Notices* for 1901 June, I compared this seasonal variation in the frequency of magnetic disturbance at Greenwich with the variation in frequency of the *Aurora* in the same locality, showing that in both phenomena there existed maximum epochs at or near the equinoxes, and minimum epochs at or near the solstices. I now desire to pursue the question a little further.

As regards the *Aurora*, although in our latitude there is, as mentioned, maximum of frequency at the equinoxes and minimum of frequency at the solstices, this condition undergoes modification in higher latitudes, the winter minimum becoming less pronounced as higher latitudes are approached, until it altogether disappears. In the recently published *Catalog der in Norwegen bis Juni* 1878 *beobachteten Nordlichter*, J. Fr. Schroeter has combined the work of Tromholt for Norway and Rubenson for Sweden, and formed abstracts that give, separately for each one of five latitudinal regions over Scandinavia, the monthly frequency of the *Aurora* as found from observations, many thousands in number, made during the years 1761 to 1877. And from a paper by Mr. R. C. Mossman "On the Aurora Borealis in London," contained in the *Journal of the Scottish Meteorological Society*, third series, vol. xi. p. 58, corresponding information is to be found for other positions south of the above. To these I have added the monthly frequency of magnetic disturbance at Greenwich and Paris. The various numerical results are given in the annexed table, in each case in percentage of the total frequency.